Fiber Bragg Grating Sensor/Systems for In-Flight Wing Shape Monitoring of Unmanned Aerial Vehicles (UAVs)

NASA Dryden Flight Research Center

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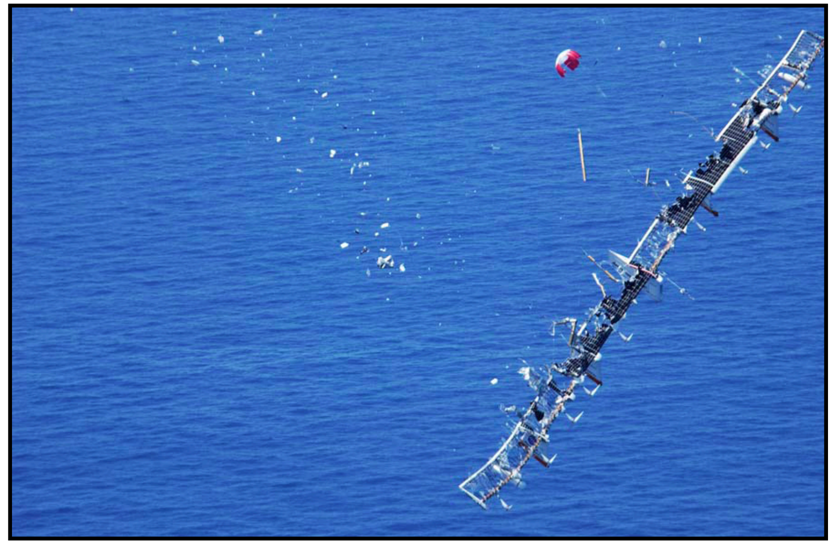
Presentation Outline

- Motivation
- Objective
- Background
- System Design
- Ground Testing
- Future Work
- Conclusions

Motivation



Helios Mishap Report – Lessons Learned

LL.2) **Measurement of wing dihedral in real-time should be accomplished with a visual display of results available to the test crew during flight.**

LL.3) **Procedure to control wing dihedral in flight is necessary for the Helios class of vehicle.**

Helios Solar Powered Aircraft

Experiencing turbulence after taking off on first solar powered flight

July 14, 2001

Dryden Flight Research Center

Objective

- **Develop an in-flight wing shape measurement system based on fiber-optic strain sensing technology for use on Helios class of UAVs**
- **Validate sensing technology on similar composite material in a ground-test environment**
- **Reduce weight of measurement system for flight applications**
- **Integrate sensor system for flight support**

Background: Measurement System Development

- **Measurement system requirements (Pathfinder+)**
  - Distributed sensing capabilities
  - Lightweight sensors / system
    - Small form factor (1 ft^3)
    - Low power (<15 Watts)
    - Light weight (<5 pounds)
    - Local Processing
    - High-speed serial interface (CAN)
    - Local mass storage
- **Dihedral measurement for spar wing structure**
  - Development / verification of analytical prediction capabilities

$$\bar{\varepsilon}_i = \frac{\varepsilon_i}{\cos\phi_i \cos\gamma_i}$$

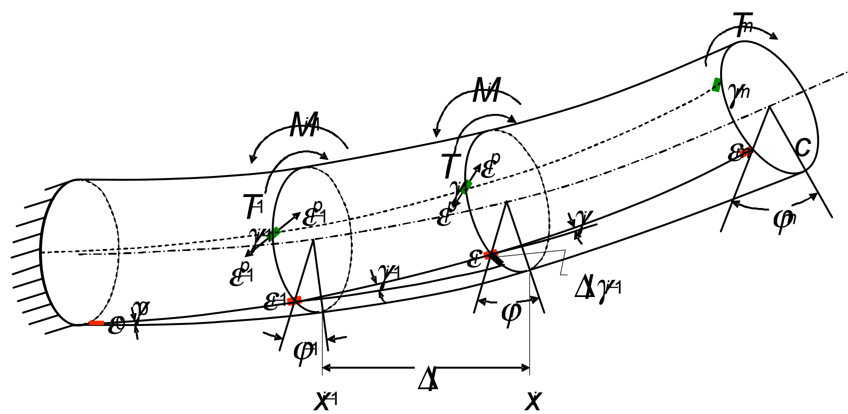
Pure Bending

$$y_n = \frac{\Delta l^2}{6c}\left\{(3n-1)\varepsilon_0 + 6\sum_{i=1}^{n-1}(n-i)\varepsilon_i + \varepsilon_n\right\}$$

Pure Torsion

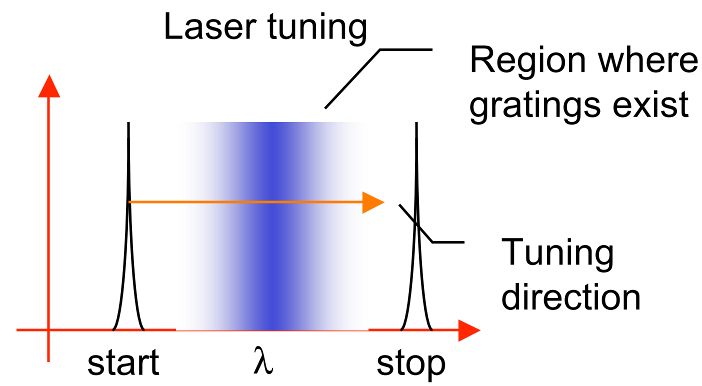
$$\phi_i = \frac{\Delta l}{c}\sum_{n=0}^{i-1} 2(1+\nu)\varepsilon_i^p$$

Combined Bending and Torsion



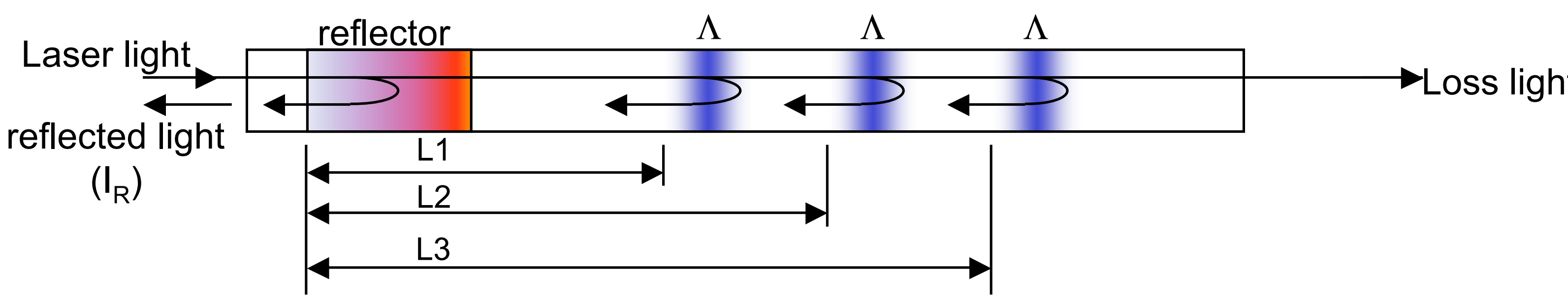
Background: Fiber Bragg Gratings (FBG)

- Multiplex 100s of sensors onto one fiber
- All gratings are written at the same wavelength
- A narrowband wavelength tunable laser source must be used to interrogate sensors
- 0.1 mm to 100 mm Gage lengths

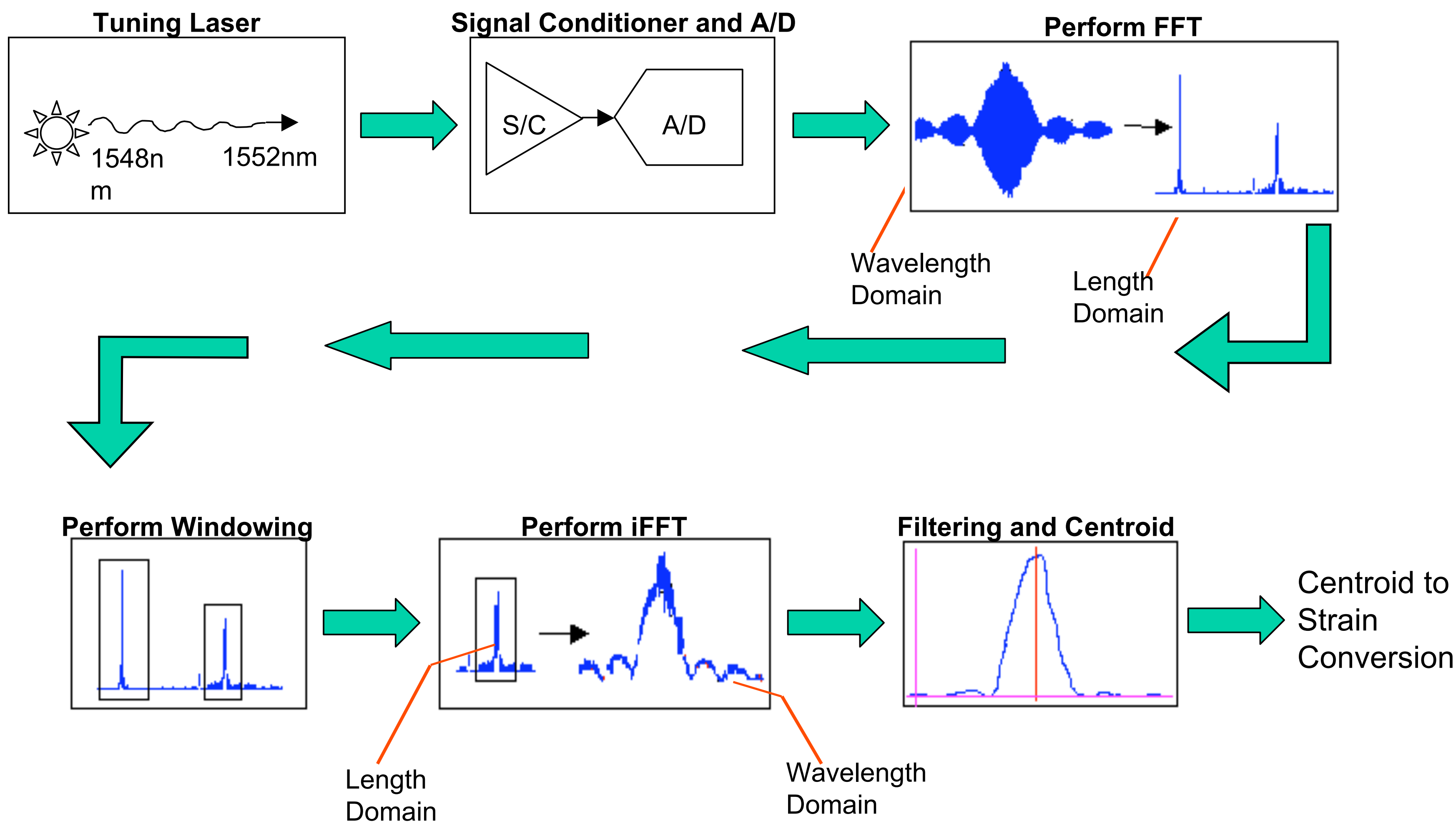


$$I_R = \sum_i R_i Cos(k2nL_i) \qquad k = \frac{2\pi}{\lambda}$$

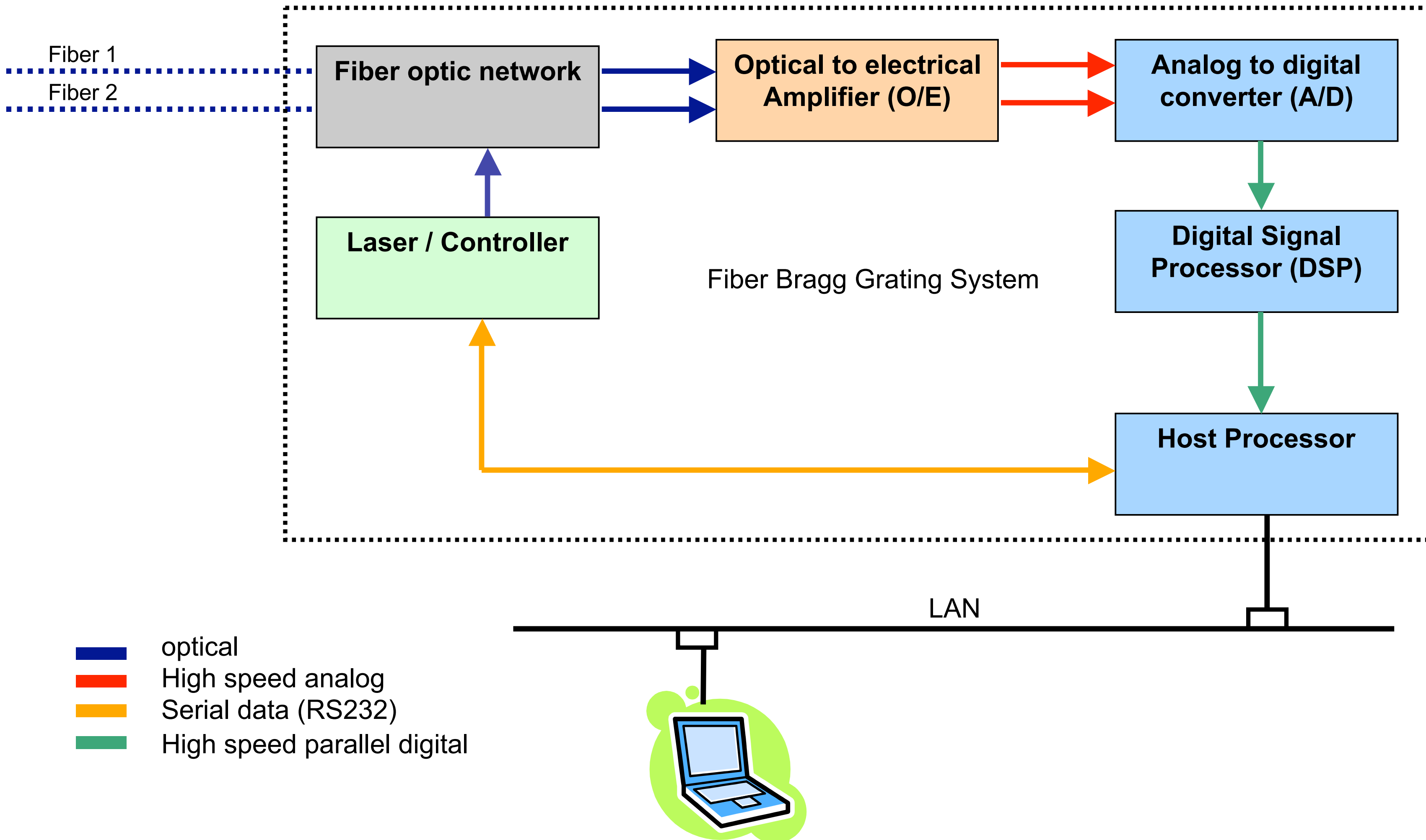
R_i – spectrum of i^{th} grating
n – effective index
L – path difference
k - wavenumber



Background: Langley Bragg Grating Interrogation Process



Background: System Component Diagram



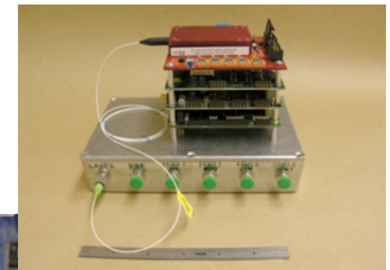
Background: System Evolution

System I - Desktop PC, table top laser, network box (~65 lbs)

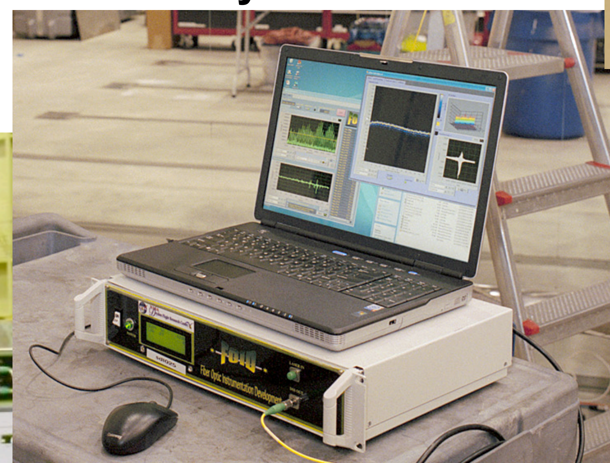
System II - Notebook PC, Integrated box with mini laser, CPU, and network box (~25 lbs)

System III - Integrated PC104+ Stack with host CPU, mini laser, DSP and network box (<5 lbs)

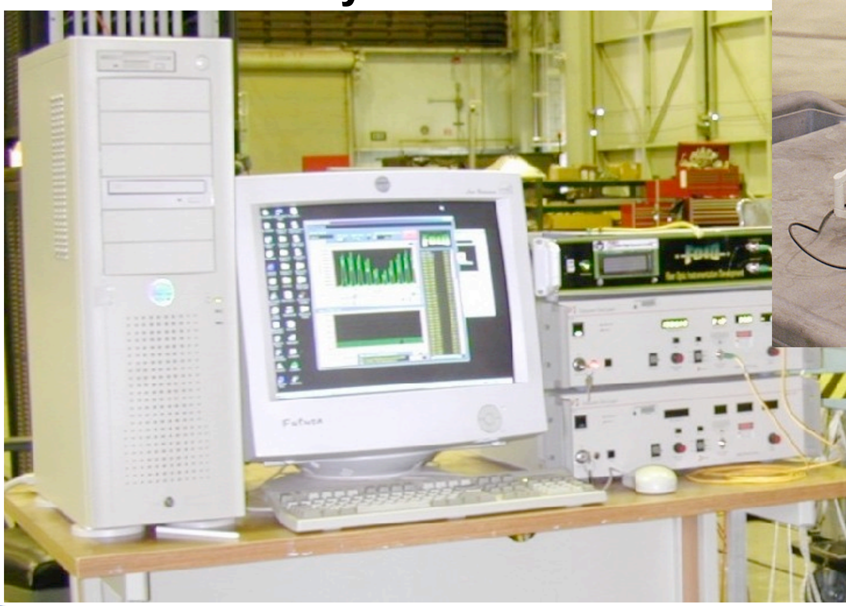
System III



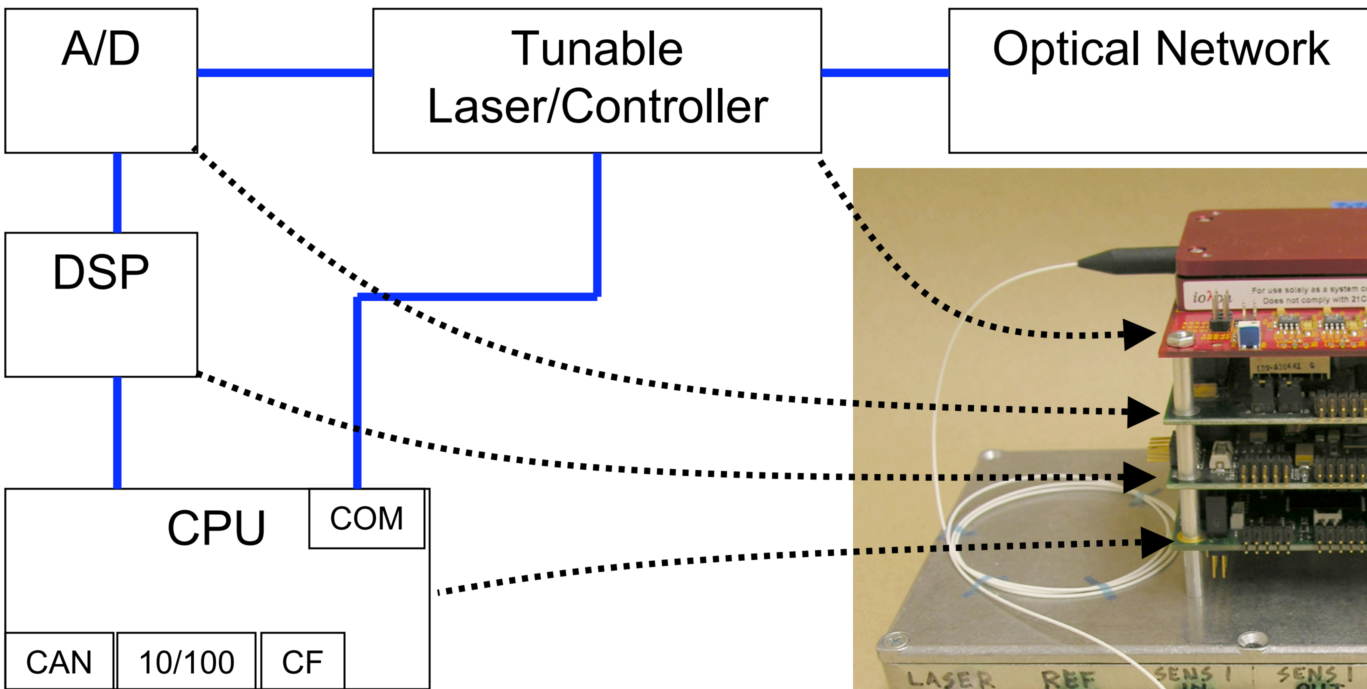
System II

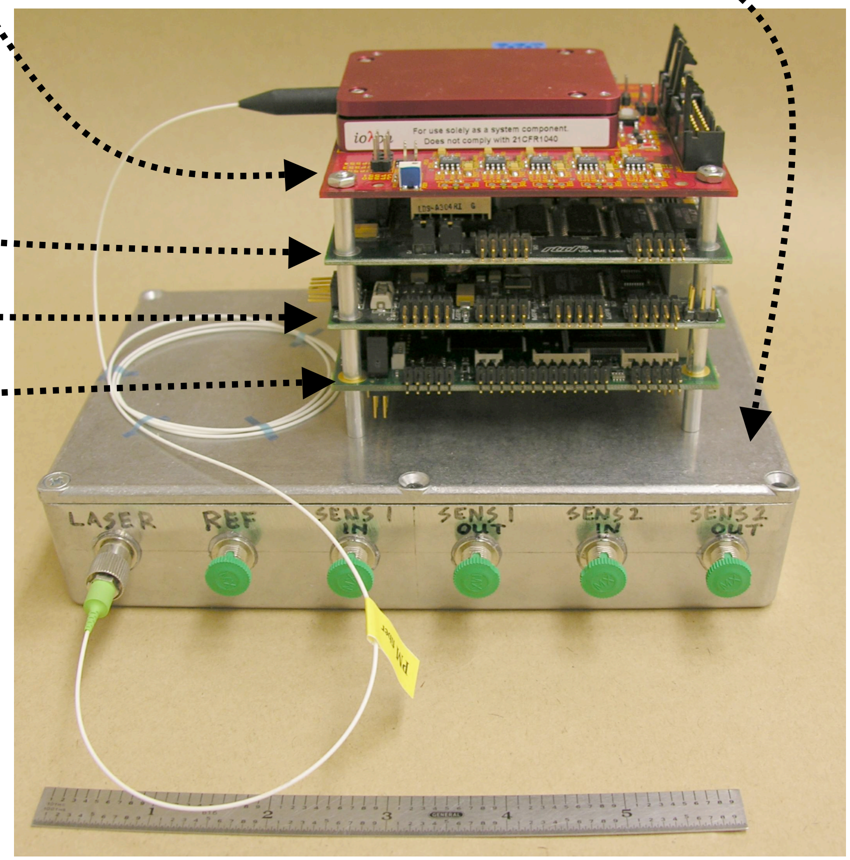


System I



System Design: Block Diagram

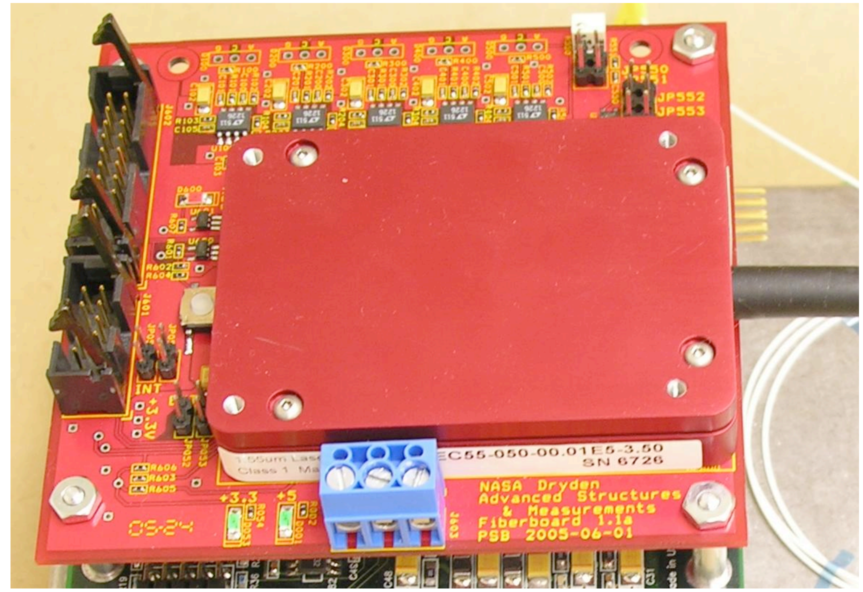




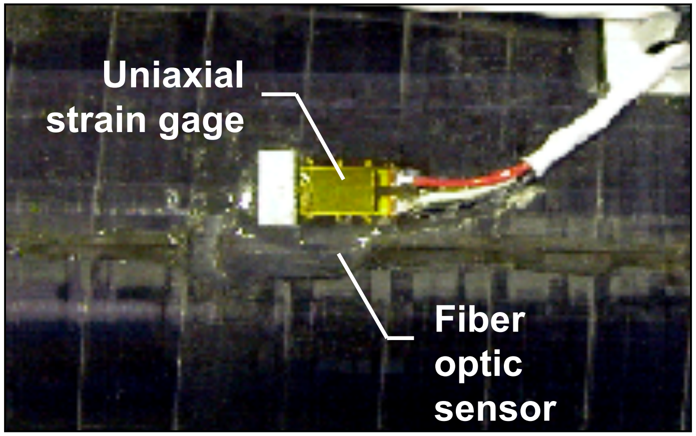
Specifications:	
Size:	7"W x 5"L x 6"H
Power:	~10 W @ 5V
Weight:	3 lbs
Channels:	2
Measurements / channel:	480 / channel
Host Interface:	CAN, 10/100
Storage:	8 GB
Sample rate:	0.5 s/s

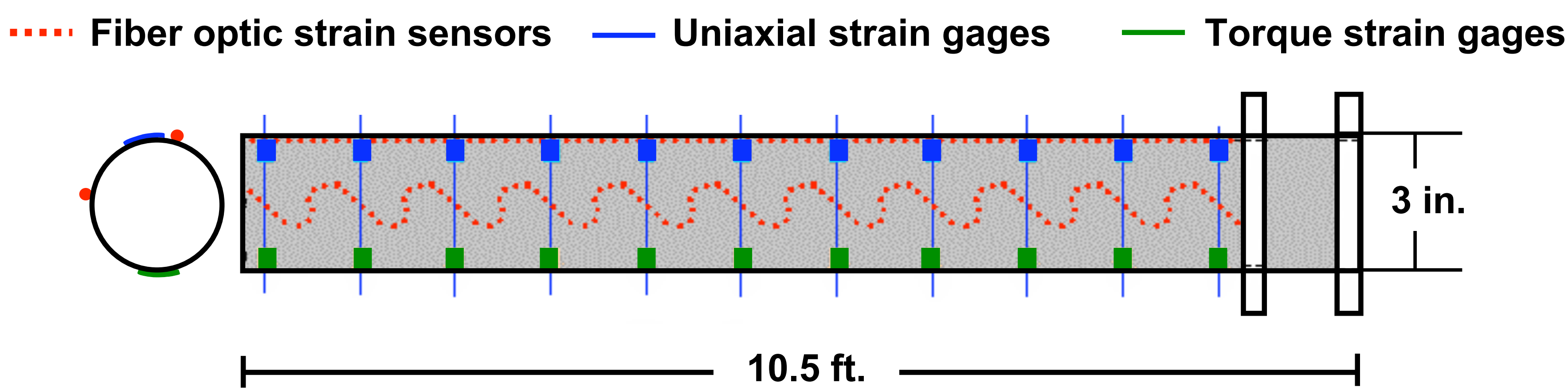
System Design: Subcomponents

- **Optical Network**
  - 80 ft reference fiber (20 sensing feet)
  - 2 sensor fibers capable
- **Tunable Laser / Controller**
  - MEMS C-band 10mW tunable laser (5.5W)
  - Serial interface
  - Four channels of optical-to-electrical amplifiers
- **Analog-to-Digital Converter (RTD)**
  - 12-bit resolution
  - Two channel capable
  - 1.25MHz sample rate
- **DSP (RTD)**
  - TI C6202 @ 233MHz (3W)
- **CPU (Kontron)**
  - Low power 133MHz Pentium (4W)
  - 8 Gigabyte compact flash adapter
  - 10/100 Ethernet and CAN bus interface

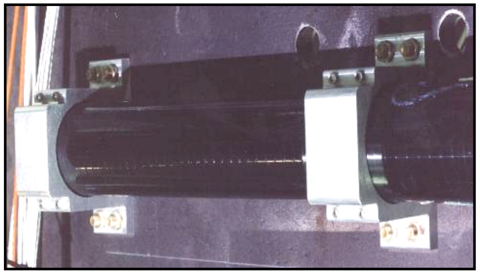


Ground Testing (Turbo Boom)

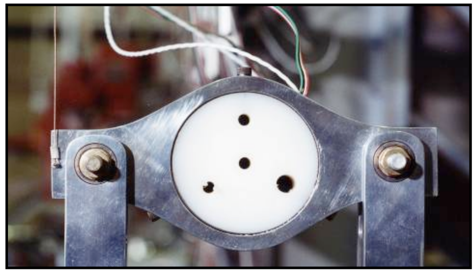




Ground Testing (Turbo Boom)

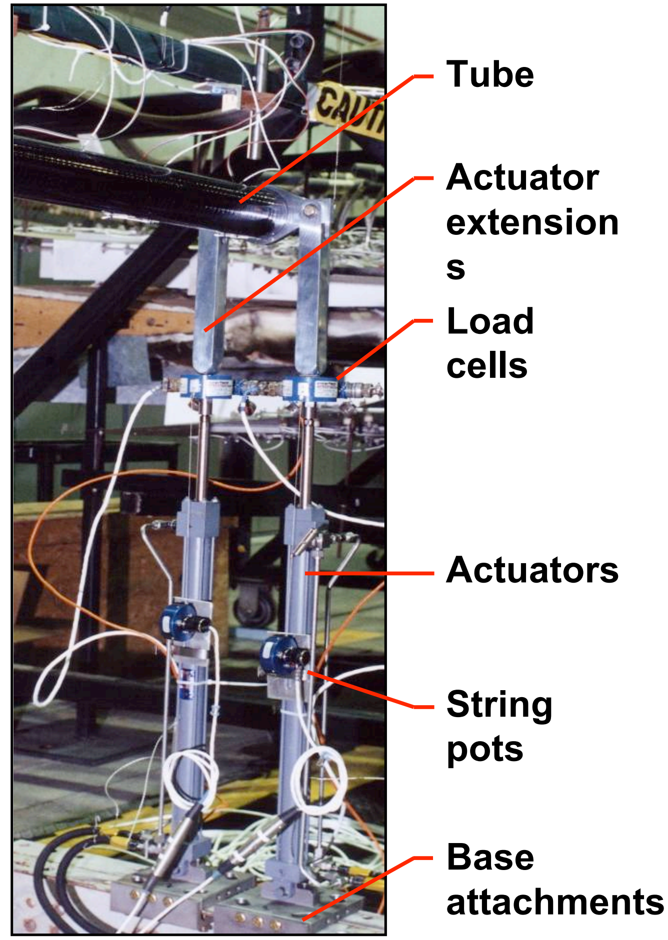


End Restraint



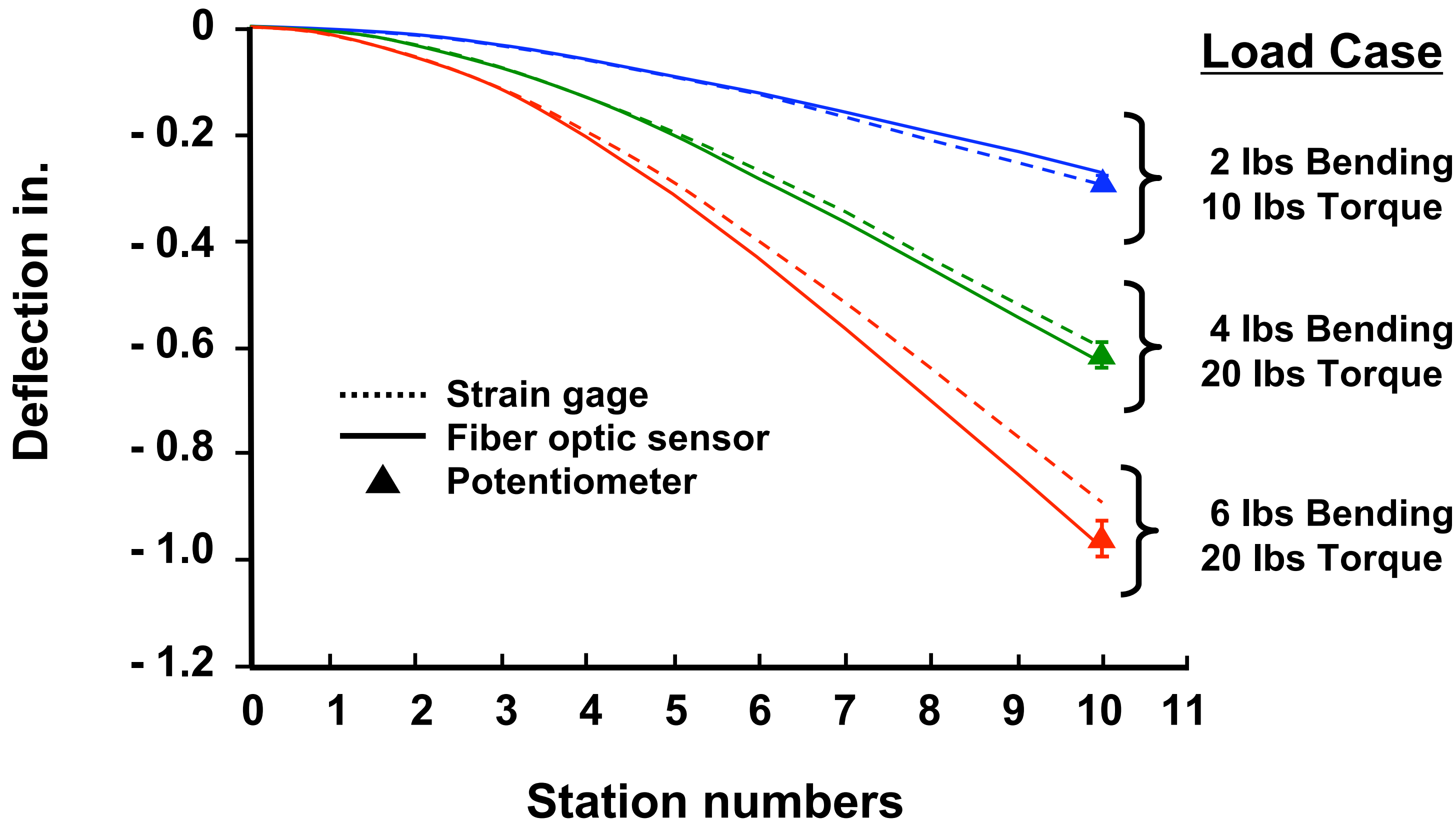
Load Application

Composite tube during test

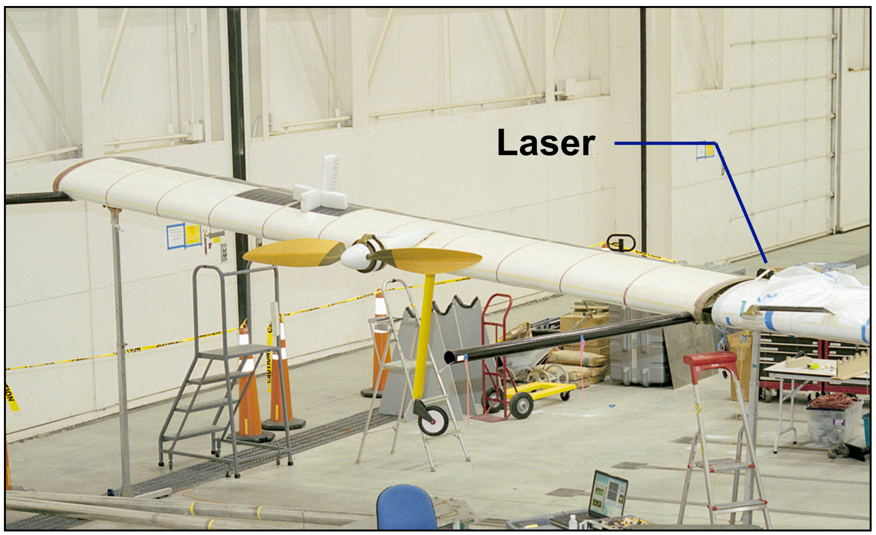


Ground Testing Results (Turbo Boom)

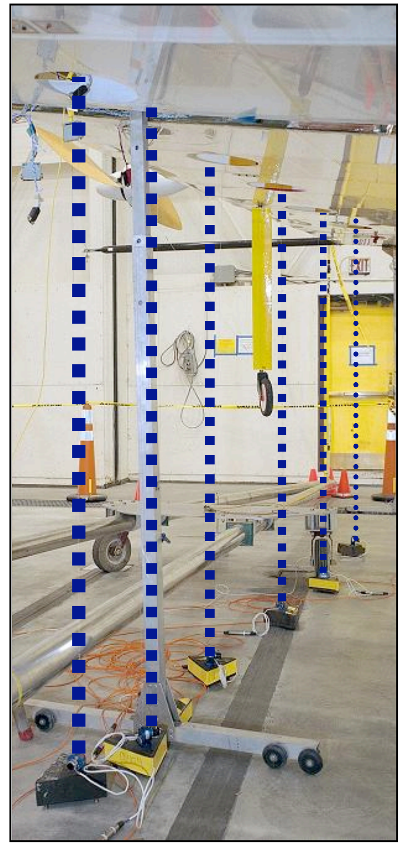
FBG displacement correlates within ~ 3 - 5% of deflection measurement



Ground Testing (Composite Wing Spar)



Outboard Wing Section

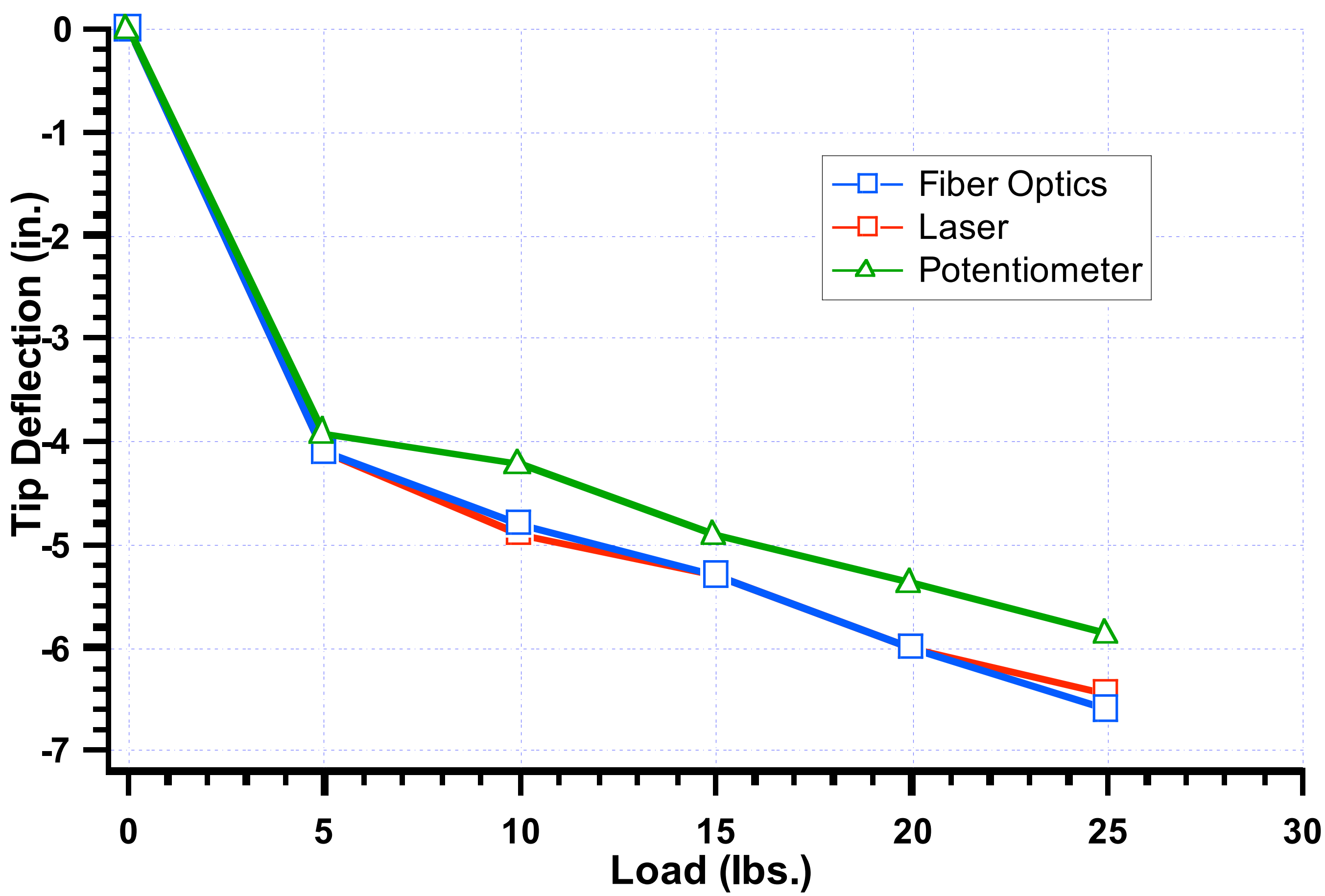


Potentiometers

Fiber Optic System

Ground Testing Results (Composite Wing Spar)

Outboard Wing Section Test Results



Future Work

- Improve system for more aggressive environments
- Develop a higher performing version of the measurement system for less power restrictive aircrafts
- Develop a next generation high performance ground system that will accommodate 32 sensing fibers
- Investigate other processing techniques / algorithms to reduce processor load

Concluding Remarks

- **Fiber-optic based wing deflection measurement system is a viable method for real-time wing deflection determination on high aspect ratio UAVs**
- **The system can predict wing deflection, and shape with little structural impact or added weight**
- **It was shown that the shape algorithm correlate well the conventional deflection measurement techniques (within 3% to 5%)**
- **It was shown that FBG strain sensors correlate well with conventional stain gages with both sensors using the shape algorithm**